Automotive

Power Management

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1. Introduction

Every automotive application can be divided into functional blocks in terms of the electronics that they contain. First of all, there are electronic blocks that deal with power and electronic blocks that deal with information. Bot of them have an interface to the surrounding environment and a main hub for processing the information or power.
In this respect the power electronics blocks are:

- Power Input Protection
- Power Management

While the signal electronics blocs are

- Communication Interface
- Signal Processing

These four blocks define a basic automotive Electronic Control Unit (ECU). However, there is no use of having an Automotive ECU without its main functionality. A fift block is therefore necessary in order to provide the means for controlling the main functionality of the application:

- Load Management

Therefore, the Load Management block is specific for every application: LED drivers for lighting units; MOSFET inverters for BLDC drivers; radar transmitters; camera lenses; lasers for lidars; amplifiers for audio and antennas for wireless communications.

The first four blocks are universal for most applications in their nature. However, there might be a difference in their scales. A central computer or ADAS control unit might have a large Signal Processing requirement that would require fast Communication Interface and substantial power requirements for the Power Management and Input Protection blocks. Compared to a lighting module that would still require substantial power but much less signal processing and communication bandwidth.

The interconnections of these blocks within the application of a Zone Control Unit are displayed below in Fig. 1.

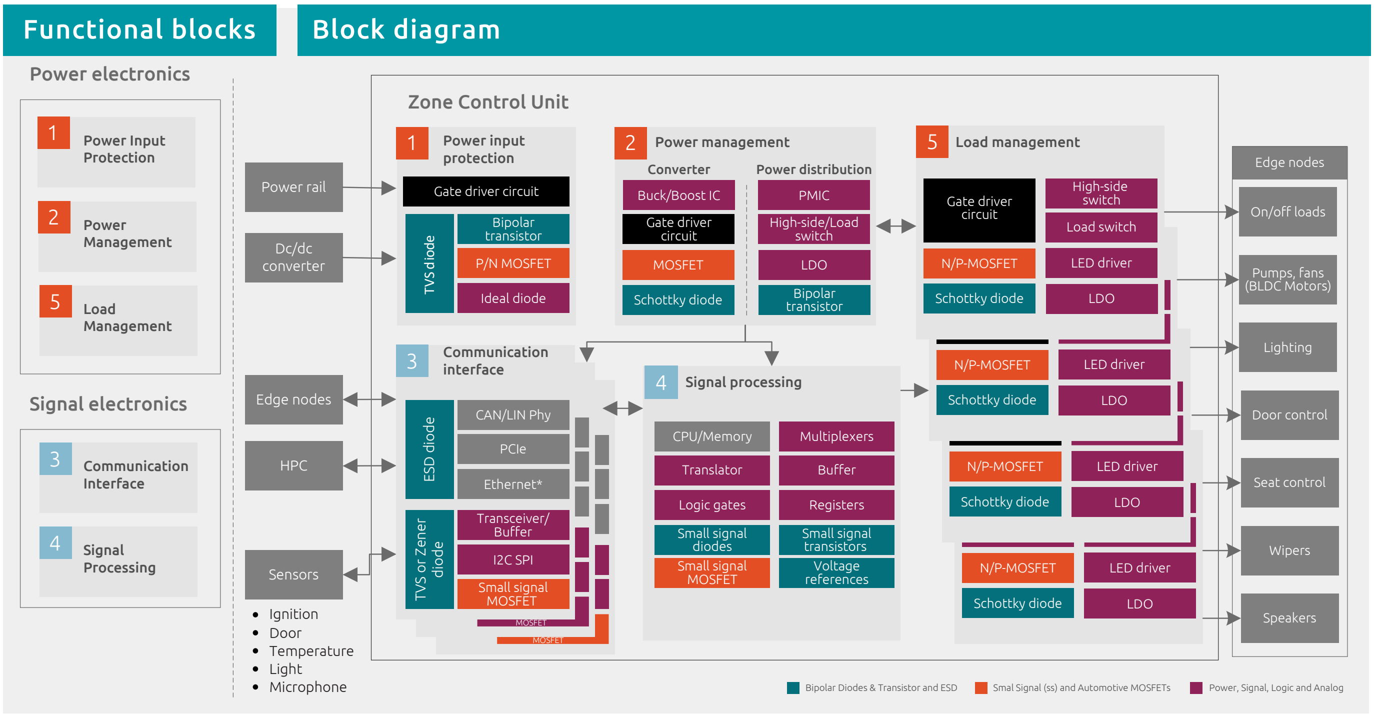


Fig. 1 Zone Control Unit internal electronics block diagram

As the main function is distribution of power and communications to the local actuators, the corresponding blocks appear multiple times.

1 The Power Input Protection block can take up substantial size and large power devices. Besides protecting the rest of the circuit from power surges it can also interconnect various energy supply sources like the batteries and dc/dc converter. It is important to protect the supplies in case the other collapses. It can also appear in several voltage levels like 12 V and 48 V in case the vehicle contains both power nets.

2 The Power Management block contains the means for transforming the incoming voltage to a level that is suitable for the rest of the components. The resulting voltage rails are used to fuel the signal processing and communication blocks. In vehicles with 48 V board nets, this is the place to transform the 48 V to 12 V or 16 V to supply legacy actuators. This might be done via high power resonant converters, such as the Switched Tank Converter.

3 The Communication Interface block consists of a variety of communication protocols. Some of these could be analog and slow digital inputs towards sensors. Somewhat faster like IVN and ESD towards information rich periferals such as ADAS cameras and radars. Audio signals can be transmitted to local speakers and received from microphones. Finally, the received information is translated and packed in a fast Ethernet protocol to communicate with other ZCU units and the central High-performance computer. All of these information feeds need to have appropriate protection via ESD or TVS diodes, according to the speed and strength of the signal.

4 Finally, the Signal Processing block contains the Controller and Memory blocks. From the Nexperia arsenal logic gates and registers can be used to establish additional layers of logic and safety that are independent of the main controller; small signal discrete devices can be used for conditioning signals from nearby sensors; and multiplexers and analog switches to increase the digital and analog input channels of the controller.

In this techbook the Power Management block is described in more detail. The challenges a designer might face are addressed with a proposal of appropriate devices and their design in procedures.

2. Design Challenges and Solutions

The design of the Power Management block depends on the incoming voltage level, the power needs and the required internal voltage rails of the application. The power distribution is also a part of the Power Management system.

2.1. Stabilizing and converting the incoming voltage to a level suitable for the rest of the sections of the system.

The incoming voltage from the vehicle power rail can be 12 V, 24 V or 48 V. The voltage can be relatively unstable because of the long lines and wide variety of loads attached to it.

Applications can be a place for voltage conversion in various amounts of power. There are devoted dc/dc converters, that are standalone or placed within a ZCU, that convert 48 V to 12 V at high power levels in excess of 500 W. Converters within specific applications can also convert at low (<100 W) or medium power levels (100 W to 500 W) depending on the application requirements. These three power levels are addressed separately below.

a) Central converter for 48 V to 12 V (>500 W)

To address these power levels some sort of resonant converter is used. The most common technologies are adopted to automotive standards from the realm of web servers: the Switched Tank Converters (STC). Their operational principle is briefly described on Fig. 2. The circuit operates with just one PWM signal. In T_{on} phase the bold MOSFETs are ON, the rest are blocking. Capacitors C_1 and C_3 are being charged from V_{in} and C_2. The resulting current is fed through to the output. In the T_{off} phase all the MOSFETs change switching state. Capacitor C_2 is charged from C_1 and C_3 is discharged to the output. The resulting voltage at the output is therefore one quarter of the input. The inductors coupled with the capacitors create current and voltage fluctuations. This enables the switches to commutate at zero current, eliminating most of the switching losses.

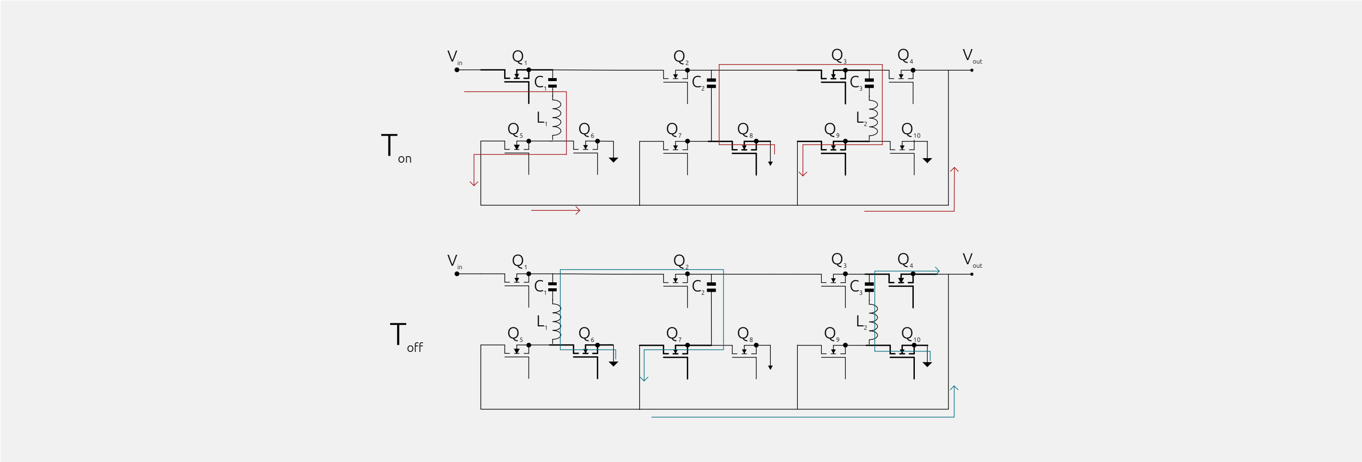


Fig. 2 Switched Tank Converter operational principle

The inductor currents are summed at the output, and at high power ranges these can amount substantially, requiring large MOSFETs, sometimes used in 3-4 in parallel. To reduce the number of MOSFETs in parallel, Nexperia's CCPAK1212 MOSFETs are a good choice.

Suggested Nexperia CCPAK1212 MOSFET devices

Package
- Offering Bottom Cool & Top Cool (inverted) Package with copper clip
- AEC-Q101 Automotive qualified
- Become JEDEC standard (MO359) open for 2nd source compatibility

Manufacturability & Robustness
- Flexible leads for temp cycling reliability
- Compatible with SMD soldering & AOI

Manufacturability & Robustness
- Low inductance
- Current spreading
- Tested high ID max rating

High Power Density with very low $R_{DS(on)}$
- Targeting multi-parallel connection system
- Less component count
- Better transient thermal performance

Top Side Cooling Package Option
- Less thermal Impact on PCB
- Better thermal optimization with larger heatsink for thermal efficiency

High Performance Silicon
- 0.2 mΩ 40V
- 0.4 mΩ 80V
- 0.99 mΩ 100V

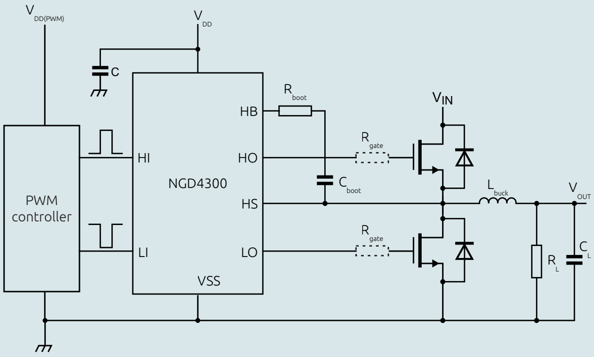
The MOSFETs are there to control the current and voltage applied to the load. However, the load needs to be controlled according to the needs calculated by the application MCU. The link between the signal conditioning controllers and the power switches are the gate drivers. To select a gate driver, the application's power requirements, MOSFET gate characteristics, and specific needs like isolation and protection need to be considered. Key factors include gate drive voltage, current or switching speed power supply voltage.

When selecting a gate driver, it is important to ensure the driver can provide the necessary voltage and current to fully drive the MOSFET gate. As the current capability of the gate driver determines how quick the MOSFET input capacitance is charged, it also effects the MOSFET switching speed. Integrated drivers are ICs so manufacturers can implement a host of functionalities like isolation (to protect control circuitry from high voltage or noise), under voltage lockout (UVLO), over-current protection, and over-temperature shutdown.

Suggested Nexperia integrated gate driver: NGD4300-Q100 – 120V 4A HS/LS

Automotive quality
- Automotive Qualified to AEC-Q100 standard
- Available evaluation board

Performance
- Supply range 8 to 17 V
- V_{HS} -5 to 115 V
- V_{HB-HS} -0.3 to 20 V
- HI and LI -10 to 20V tolerant
- I_{pk} +4/-5 A at 12 V
- t_{pp} 13 ns (typ.);
- T_r 4ns and T_f 3.5ns @ V_{dd}=12V, C_{out} =1nF



Features
- TTL and CMOS compatible inputs
- Integrated Boot strap diode
- Input independence with V_{DD}
- Under Voltage Lock Out on both HS & LS drivers
- Delay matching 1 ns (typ.)
- SOI technology preventing latch-up of the output driver stages

Application
- Half- and Full-Bridge Power
- Converters
- Motor drivers

b) Medium power converters realised with discrete components

In larger ECUs data processing can be power hungry. The power conversion can also be realised for the supply of local actuators and sensors, building up to and above the 100 W mark.

In these cases traditional half bridge switching converters are used with a controller and external discrete switches. These switches should excel in switching behaviour: low losses and spiking for improved efficiency and EMC performance of the converter.

Datasheet parameters can be inconclusive when it comes to switching behaviour. To compare available MOSFETs effectively, engineers should perform their own double pulse testing (illustrated in Fig. 3) to find a device with the best efficiency and switching behaviour ratio. More information can be found in Nexperia Application Note AN90011.

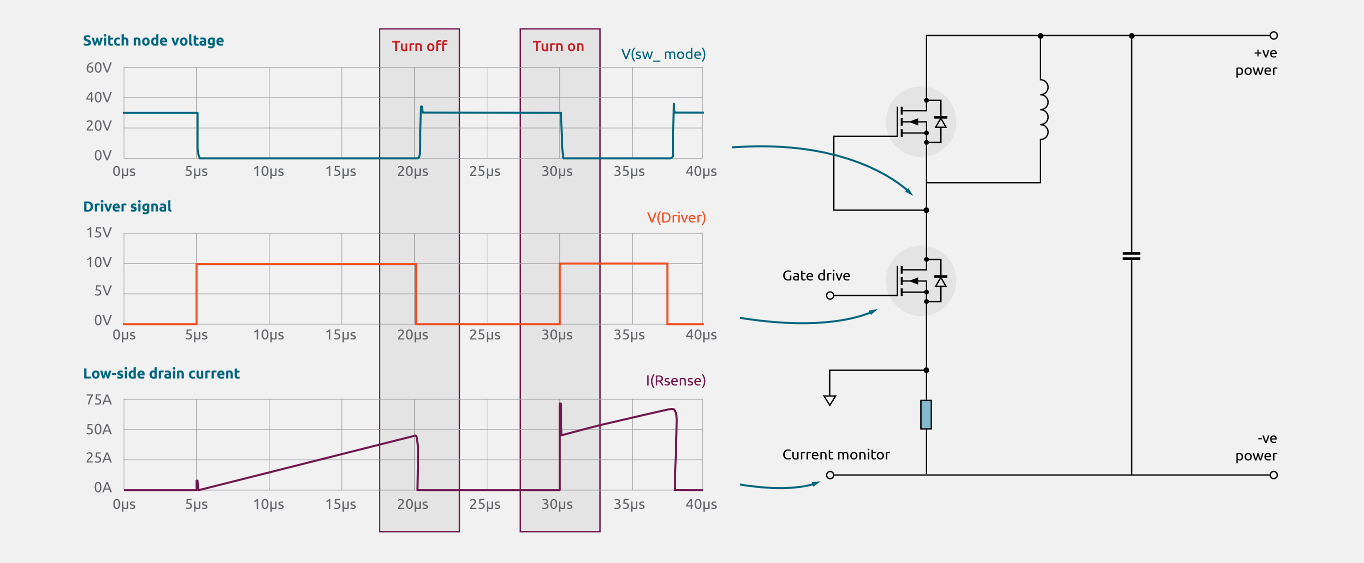


Fig. 3 Double pulse testing waveforms and circuit

Nexperias newly introduced T12 technology MOSFETs target such applications. They are available in suitable small packages: LFPAK33 (3x3mm) and LFPAK56D (5x6mm dual). Their switching behavior is illustrated in Fig. 4 as a result of an in-house double pulse testing project. The ideal way to implement a MOSFET in a dc/dc converter is to target the desired spiking (64 V on Fig. 4) and efficiency on the turn on switching while maximizing switching speed at turn off, as there is no danger of excessive spikeing in the switching waveforms.

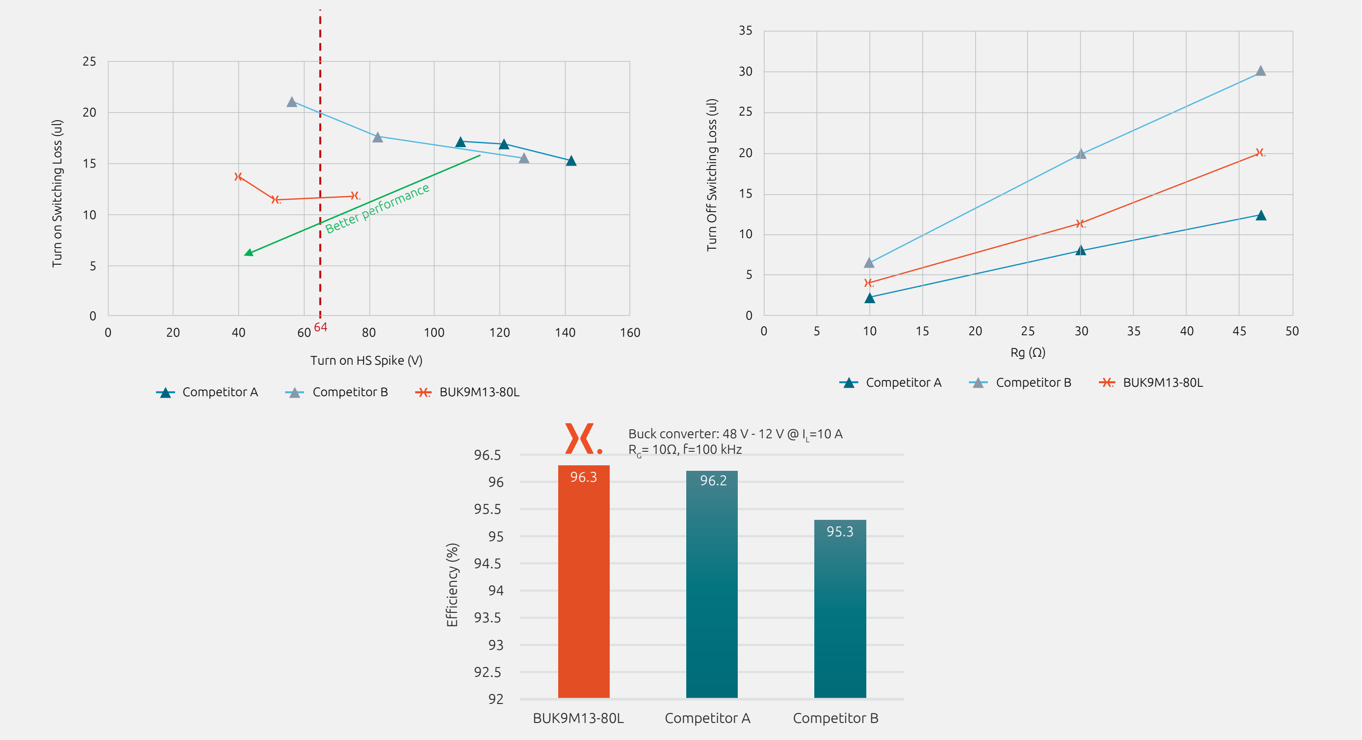


Fig. 4 T12 technology MOSFETs switching performance benchmarking

The freewheeling MOSFET can be replaced by a switching diode [AN11550] as seen in Fig. 5. This move simplifies the control and design of the circuit but increases conduction losses. The employed diode should have low forward voltage drop and leakage current, as well as good heat dissipation capabilities. For more details on diodes, please see Nexperias Diodes Handbook.

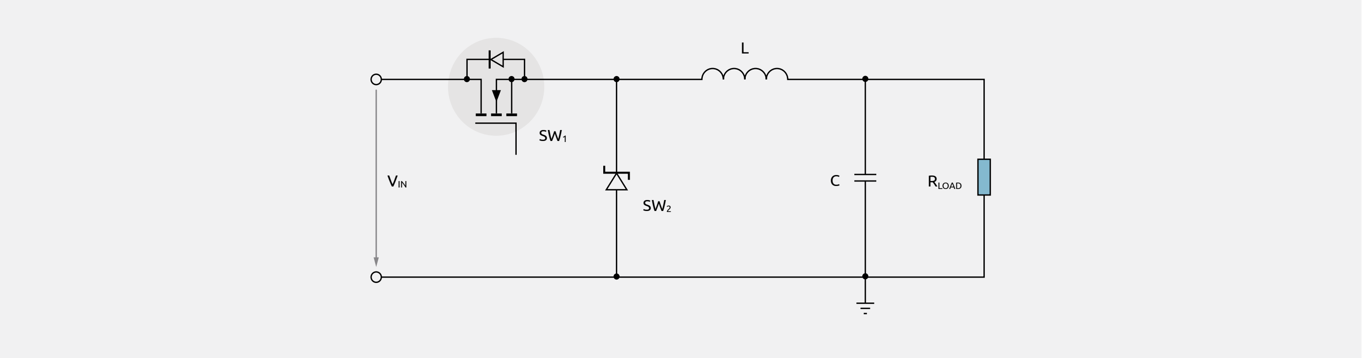


Fig. 5 Asynchronous Buck converter with MOSFET and Schottky diode

Nexperia's Trench technology Schottky diodes show very good switching behaviour. Compared to their planar counterparts they have lower reverse recovery charge and smaller reverse recovery current overshoot. This results in a better efficiency at high switching frequencies, which in turn results in less losses and cooling requirements of the converter. This is shown in Fig. 6 in case of a 48 V to 12 V switching converter.

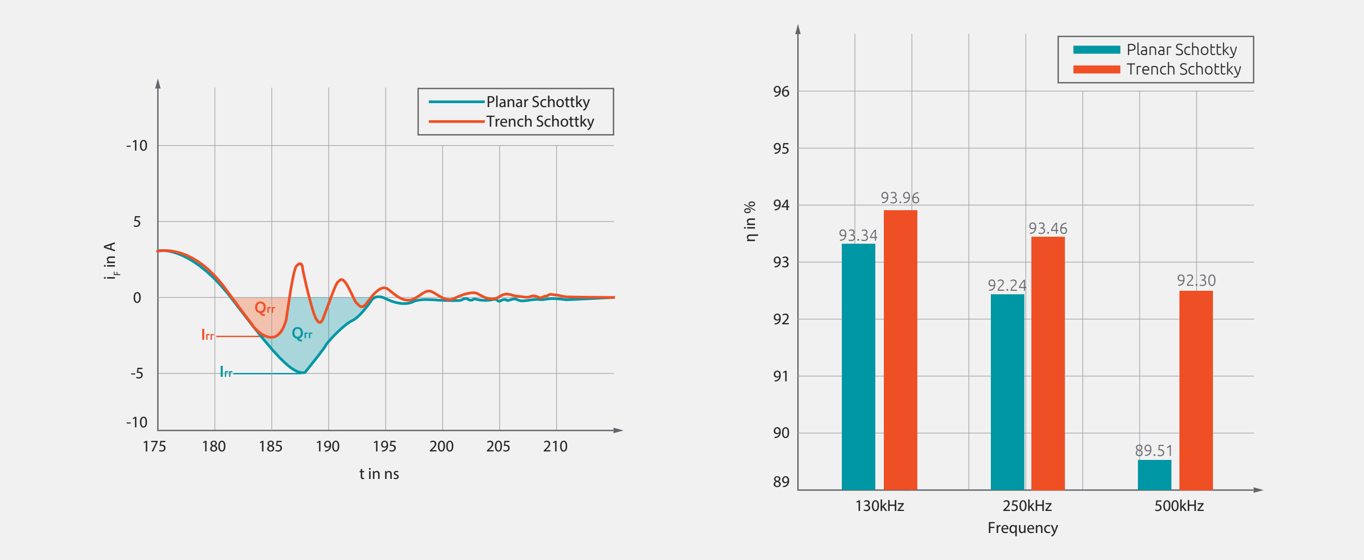
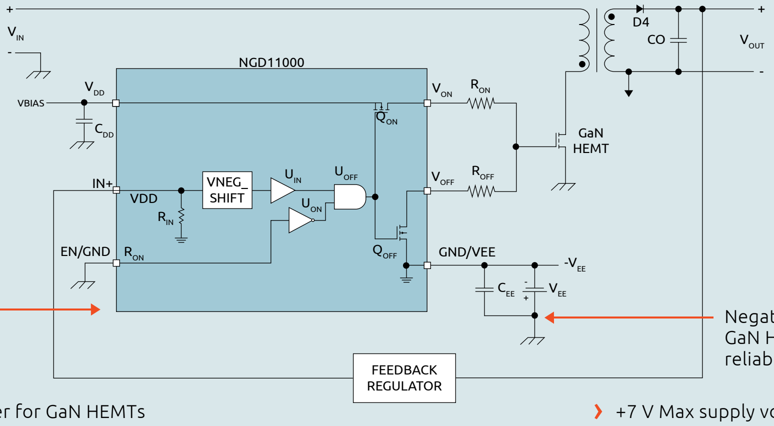


Fig. 6 Trench Schottky diode behaviour in a 48 V to 12 V switching converter: reverse recovery waveforms (left) and converter efficiency (right)

c) Low power converters with integrated power devices

Nexperia also offers a complete automotive low voltage GaN converter solution with gate drivers for E-GaN devices. The gate drivers can be implemented in converters with extra high switching frequencies – up to 60 MHz. It features simple design for fast propagation delays and small minimum pulse width. The charging and discharging gate drive strength is resistor adjustable and the negative off-state voltage is selectable for improved noise immunity. These gate drivers can be coupled with AEC-Q101 GaN FETs like the GANE011-080CBA. The GaN FETs have low R_{dson} for the small package they are hosted in (3.5 x 2.1 mm WLCSP) which helps with current conduction but limits the cooling. The low R_{dson} is coupled with low reverse recovery and output charge, achieving high switching frequencies with low noise generated. This solution is suitable for power supplies with up to 100 W and high switching frequency, implying fine control of the output voltage.

Suggested Nexperia E-GaN HEMT driver: NGD11000



High current drivers with extremely fast output rise/fall times for higher efficiency at MHz switching frequencies

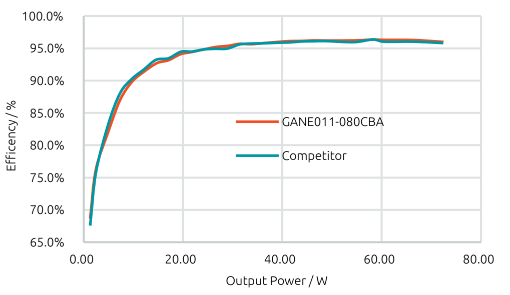
Negative off-state voltage for GaN HEMTfor improved switching reliability

- Low side, ultra fast gate driver for GaN HEMTs
- 1 ns minimum pulse width
- Up to 60 MHz operation
- 3.0 ns typical, 4.0 ns maximum propagation delay
- 350 ps typical rise and fall time into 100 pF
- 7 A peak source and 5 A peak currents
- +7 V Max supply voltage
- Support negative off-state voltage down to -2 V
- Undervoltage (UVLO) protection
- Overtemperature (OTP) protection
- 0.8 mm x 1.2 mm WCSP (6) package
- 2.0 mm x 2.0 mm WSON (6) package

Suggested Nexperia AEC-Q101 E-GaN FET: GANE011-080CBA

- Low on-state resistance x area and FOM
- Very low Q_r (reverse-recovery charge) since there is no "body diode"
  - Very low reverse recovery losses
  - Reduced ringing on switch node and EMI

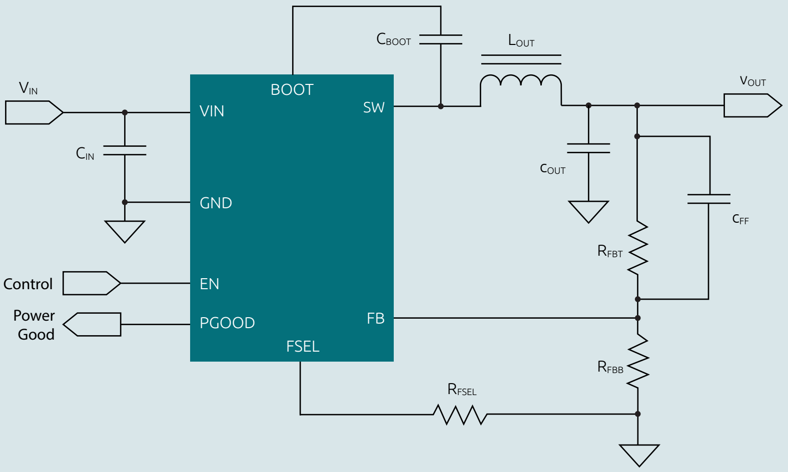
- Low C_{OSS} (output capacitance) and Low Q_{OSS} (output charge)
- faster switching, high switching frequencies
  - Reduced switching losses



Efficiency sweep for 40 V to 12 V buck converter – f_{sw} = 800 kHz, t_d = 45 ns

Voltage rails that are used only for data processing might not require discrete components. Voltage conversion can be achieved by a dedicated switching IC with integrated power devices. Such is the NEX40400 for 12 V and 24 V systems, 600 mA DC output current. These devices have a wide range of input voltage capability in a small package. They also have low standby current for low battery usage and they are also EMI friendly and easy to design in.

Suggested Nexperia integrated converter NEX40101-Q100



- Wide input voltage range from 6 V to 100 V
- Low quiescent/shutdown currents
- Integrated power FETs
- Near constant frequency adjustable up to 1 MHz
- Low min t_{ON} and t_{OFF} (100 ns / 140 ns)
- Peak & Valley current limit prevents current run-away
- Selectable PFM or FCCM operation
- Thermally-enhanced package (EPAD SO-8)

2.2 Voltage smoothing by linear regulation

Application-Specific Integrated Chips (ASICs), microcontrollers, processors and some sensors do not cope well with EMI and voltage ripple caused by switching regulators. These applications require voltages that are smoothed by linear regulation.

Linear regulators are included in almost every supply block. The difference between the inputs and outputs on these regulators are small, as well as the current that they regulate. This must be so since the difference between the inputs and outputs power is dissipated in the regulator itself. Similarly to the switching regulators, larger power requirements are fulfilled with discrete components while smaller with integrated regulators.

As the devices are required to be operated in the linear operation mode, rather than switching, bipolar transistors (BJTs) are the device of choice in this case. A solution to employing a BJT to regulate an output voltage is depicted in Fig. 7. Detailed information about BJT design in can be found in the Nexperia BJT handbook. Nexperia has a large portfolio of low V_{CEsat} devices that are suitable for linear mode applications. Table I shows a comparison of some of them.

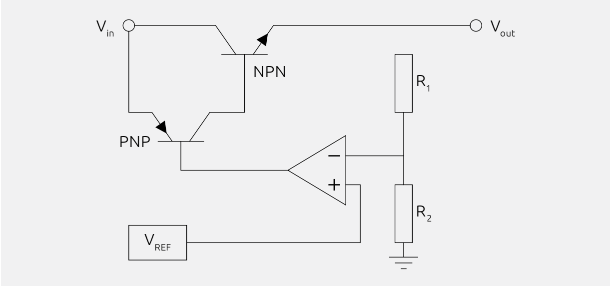


Fig. 7 LDO realisation with BJT operating in linear mode

Type	V_{CEsat} (3A) [V] (max.)	I_C [A]	H_{fe} (2A) (min.)	V_{BEon} [V] (max.)	V_{CE0} [V]	Package
PBSS4310PAS-Q	0.11	3	275	0.845	10	SOT1061D
PBSS4620PA-Q	0.17	6	260	0.9	20	SOT1061
PBSS4021NX-Q	0.1	7	300	0.85	30	SOT89
PBSS4330X	0.3	3	180	1	40	SOT89

Table I Low V_{CEsat} bipolar transistors for linear mode operation

Products with “PA” in their name are available in a modern 2 mm × 2 mm leadless package, while products with “X” in their name come in a legacy SOT89 package (4.6 mm × 4.25 mm). The thermal performance of these devices for different load currents is shown in Fig. 8. Despite their small package size, the DFN2020 devices show superior thermal performance.

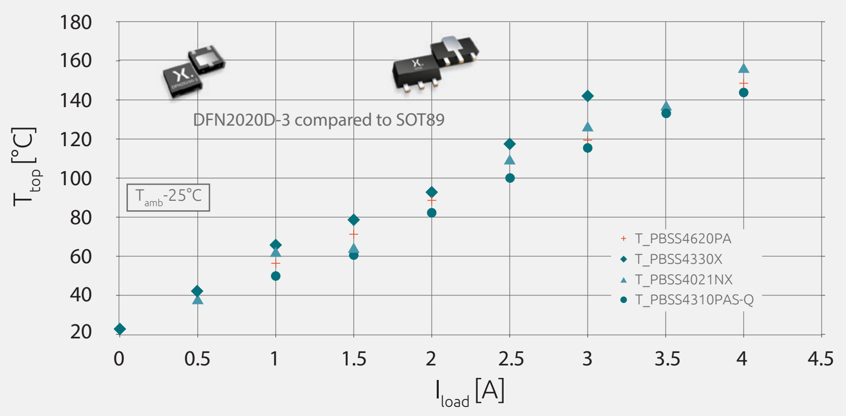


Fig. 8 Thermal performance of the BJTs for different load currents

The required reference voltage can be obtained in a few ways. Where lower accuracy voltage regulation and larger output currents (in the double-digit mA range) are required, a Zener diode, with V_Z larger or equal to the desired output voltage and the maximum base emitter voltage can be used (Fig. 9). For more accuracy shunt regulators like the TL431 or TLVH431 are used to drive the pass BJT (Fig. 10)

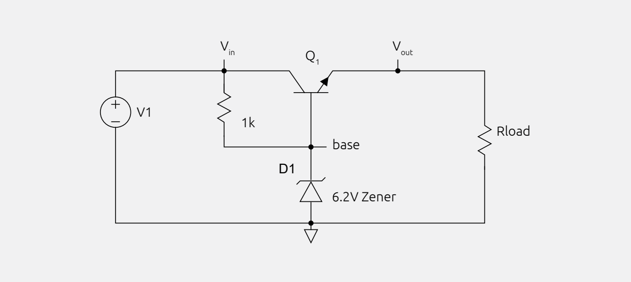


Fig. 9 Linear regulator using a Zener diode

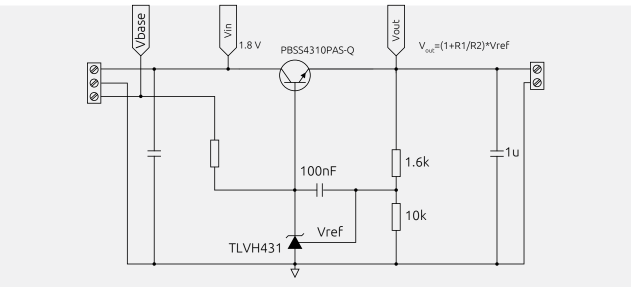


Fig. 10 Circuit schematic showing a 1.8 - 1.45 V, 3 A voltage regulator with a low-V_{CEsat} BJT and shunt regulator

In the integrated electronics arena Low dropout regulator (LDO) ICs are used for this purpose. General LDOs are used for on board MCU or communication module power rail stabilisation. Except these, there are also tracking and antenna LDOs. Tracking LDOs are intended to follow internal voltage level and transmit it to mostly off-board loads. They decouple internal voltage rails from external ones so that they remain unaffected in case of short circuit or other fault on the external cabling or PCB. Antenna LDOs are there to provide targeted voltage levels for the same loads. The antenna LDOs have accurate current sense even at light load, internal back-to-back MOSFETs saving system level costs and employ reverse current protection as well as full diagnostics to identify faults. For the summary on the roles of the different LDOs please see Fig. 11.

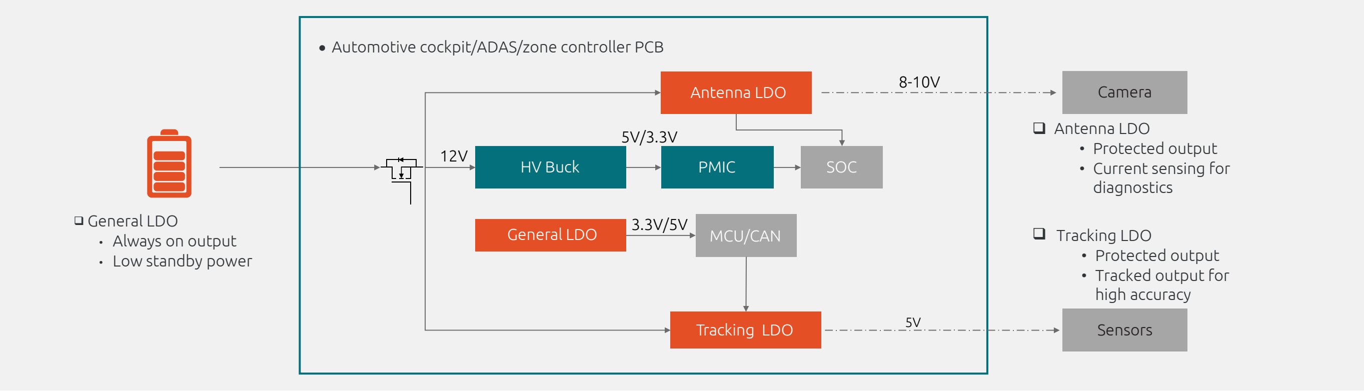
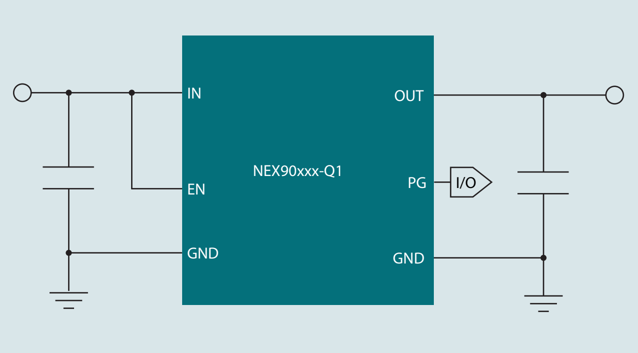


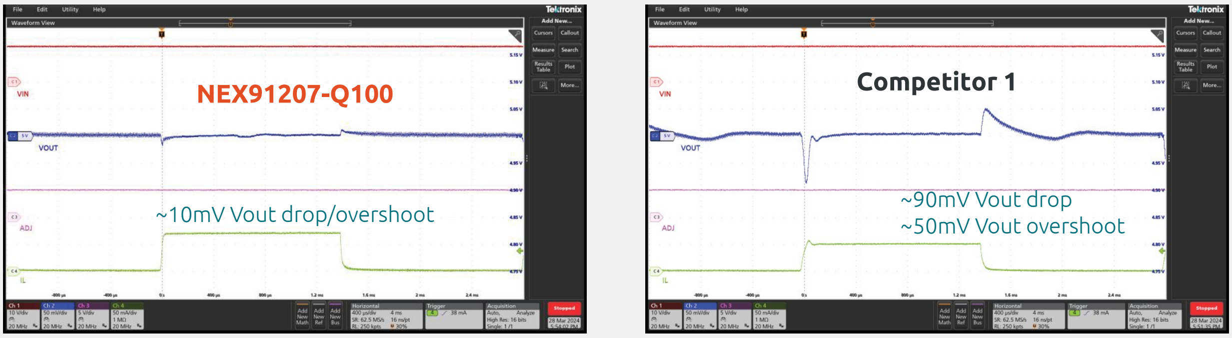
Fig. 11 Rolles of different LDO types in a controller PCB

Nexperia offers 150 mA (NEX90x15-Q100) and 300 mA (NEX90x30-Q100) general LDOs that feature low quiescent current (typical 5uA) and a wide input voltage range of up to 40 V with up to 45 V transient voltage. They are suitable for cold crank and start/stop automotive conditions. The LDOs benefit from Nexperia's expertise in package development and can handle excessive heat dissipation. The LDOs also feature an enable pin that can serve to turn a part of the circuit off when it is not needed (such can be a comms port that is not used), and a Power good pin, that can indicate a potential short circuit in the load.

Suggested Nexperia LDOs:
NEX90530-Q100 / NEX90515-Q100

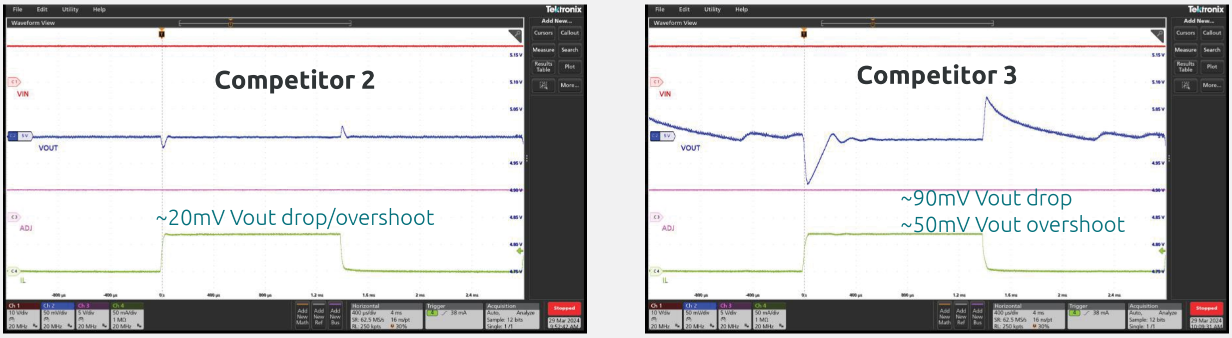


The NEX91207-Q100 (70 mA) and NEX91x15/30-Q100 (150 mA and 300 mA) are tracking LDOs. They have a variety of integrated protection features to protect against reverse current, short to battery and GND, reverse battery connection and short circuit. They have a wide input voltage range 4 V to 40 V to sustain cold crank and load dump transient conditions. The output is set by a reference voltage applied to the EN/ADJ pin and the output will track this voltage with high accuracy (5 mV tolerance). They are also availiable in packages that enable drop in replacement for popular LDOs. Fig. 11 shows an example response of the NEX91207-Q100 compared to competitors at low load transient response. It is evident that NEX part has the least amount of voltage drop and overshoot.



V_{IN}=13.5 V, 0 mA to 70 mA slew rate 0.2 A/us

V_{IN}=13.5 V, 0 mA to 50 mA slew rate 0.2 A/us



V_{IN}=13.5 V, 0 mA to 70 mA slew rate 0.2 A/us

V_{IN}=13.5 V, 0 mA to 70 mA slew rate 0.2 A/us

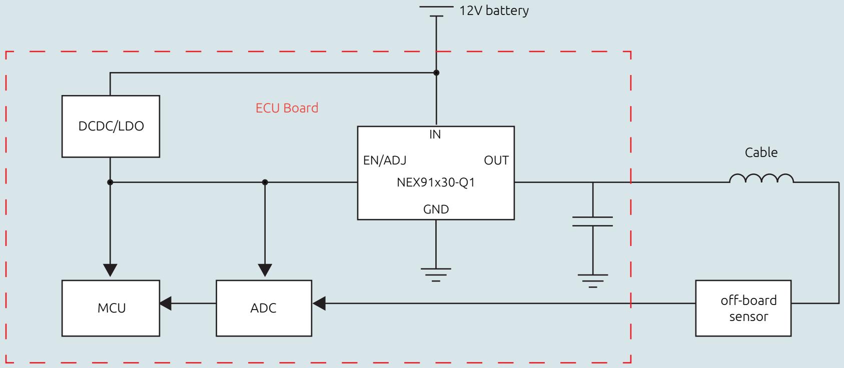
Fig. 12 Low load transient behaviour NEX91207-Q100, V_{IN}=13.5 V, 0 to 70 mA, 0.2 A/us slew rate

Part number	Txx7B4254-Q1	Txx115B0EJ	Txx7B4253-Q1	Txx4253E	Txx125D0EJ	NEX91x15/30-Q100
Output current	150 mA	150 mA	300 mA	250 mA	250 mA	150 mA / 300 mA
V_{IN} (ABS)	-40 V to +45 V	-16 V to +45 V	-40 V to +45 V	-42 V to +45 V	-16 V to +45 V	-42 V to 45 V
V_{OUT} (ABS)	-1 V to +45 V	-5 V to +45 V	-1 V to +45 V	-2 V to +45 V	-5 V to +45 V	-5 V to +45 V
Operating V_{OUT}	2 V to 40 V	2 V to 14 V	2 V to 40 V	2 V to 40 V	2 V to 14 V	2 V to 40 V
Output-tracking tolerance	±4 mV (<18 V)	±5 mV	±4 mV (<18 V)	±15 mV	±5 mV	±5 mV
$I_q/I_{shutdown}$	60 µA / 2 µA	55 µA / 0.1 µA	60 µA / 2 µA	120 µA / 2 µA	65 µA / 0.1 µA	50 µA/0.75 µA
Power monitoring	N	N	N	N	Y	Y
Cable compensation	N	N	N	N	N	Y
C_{OUT} range	10 µF to 500 µF (ESR≤ 20 Ω)	≥1 µF (ESR≤ 5Ω	10 µF to 500 µF (ESR ≤ 20Ω)	≥ 10 µF (ESR ≤ 5 Ω)	≥1 µF (ESR ≤ 5Ω)	4.7 µF to 470 µF
Package	SO- 8 EP	SO-8 EP	SO-8 EP	SO-8 EP	SO-8 EP	SO-8EP
Similarity	pin to pin compatible	pin to pin compatible	pin to pin compatible	Functional replacement	pin to pin compatible	-

Table II NEX91x15/30 tracking LDO functionality comparison with competitors

Suggested Nexperia tracking LDO NEX91x30/15-Q100

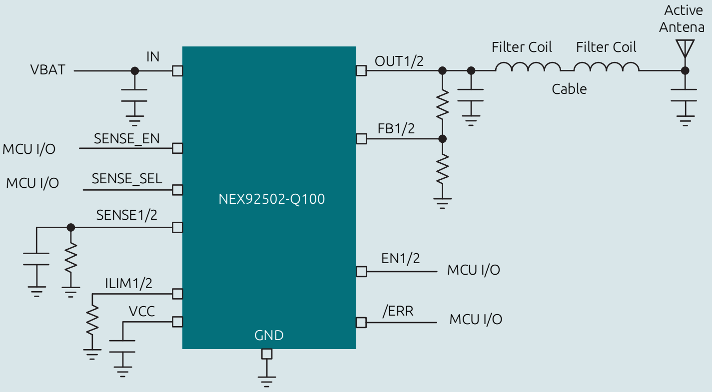
- 4 V to 40 V wide input voltage range (abs: -42 V to 45 V)
- Output voltage range: 2 to 40 V (-5 V to 45 V abs max)
- Ultra-low output tracking tolerance: ± 5 mV
- High PSRR: 80 dB@100 Hz
- Low dropout: 400 mV (typ.) @5 V/300 mA
- Low quiescent current (I_Q): 50 μA (typical)
- PG indicator for UV & OV
- Robust protection: reverse current/ reverse battery/short to battery/short to ground/thermal shutdown
- Stable with small ceramic capacitor C_{OUT}= 4.7 μA
- Active discharging
- Package SOIC-8 EP with 3 different pin-out



Antenna LDOs are similar to tracking LDOs in their intended function: supplying power to off board loads. However, antenna LDOs provide a fixed voltage rather than a tracked internal voltage level.

Suggested Nexperia Antenna LDO NEX92x30-Q100

- Input voltage range: 4 V to 40 V
- Output voltage range: 1 V to 20 V
- I2C interface supported w/ 8-bit ADC (C version)
- Dual channel o/p: 300 mA o/p current capability per channel
- High accuracy current sense: ±8 % @ I_O =5 mA
- Low dropout voltage (max. 500 mV @ 100 mA)
- Full diagnostic & protection
  - Short to battery/ground
  - Reverse battery/polarity/current
  - Open load detection
  - Thermal shutdown
- Operating junction temperature range: -40 °C to 150 °C (grade 1)
- Thermally enhanced HTSSOP-16 package/QFN-16 (I2C)



300 mA Dual/single channel Antenna LDO with current sense

2.3 Controlling the power supply to parts of the design that don't need power all the time

Parts of the design, as well as some of the off-board loads, might not need to be powered on all the time. Parts of the design like demanding processors might need to have a certain power up and down sequencing routine to prevent inrush current and other damage. In case this inrush current happens anyway, perhaps due to line impedance, it needs to be limited.

A load switch [AN50020] serves to limit the power consumption of loads that are not needed to be on. An additional role can be the protection of the loads from the damaging effects of short circuits and overvoltages by disconnecting the protected circuit. This is usually tested by applying ISO standard conducted transients to achieve compliance [AN50007].

A discrete realisation can be established with power MOSFETs. In the case of P-channel MOSFET, a single signal MOSFET is needed to control the power MOSFET. N-channel MOSFETs have superior performance to their P-channel counterparts. However, employing an N-channel MOSFET in the same position requires additional circuitry (charge pump) to pull the gate voltage above the supply line voltage in order to control the MOSFET.

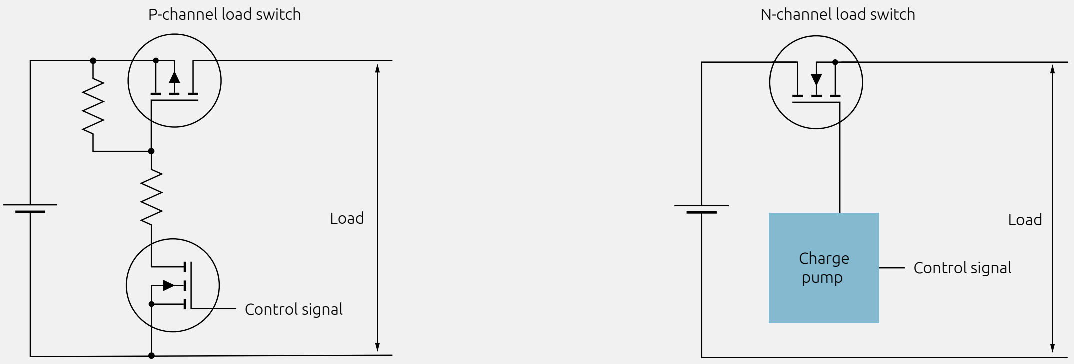


Fig. 13 Load switch realisation with P-channel and N-channel MOSFETs

Nexperia's portfolio of P-channel devices covers applications on all automotive distribution voltage levels from 12 to 48 V as well as in a range of power levels as seen in the table below.

V_{DS}	 LFPAK56	 LFPAK33	 MLPAK33	 DFN2020MD-6
20 V				19-122 mΩ
28 V/30 V	10-19 mΩ		7.5 & 21 mΩ	24, 40, 50 mΩ
40 V	14-24 mΩ		12 & 26 mΩ	43 mΩ
60 V	33-61 mΩ	61 mΩ	66 mΩ	120 mΩ
80 V	55 mΩ			120 & 220 mΩ

Table III Nexperia's P-channel MOSFET portfolio

For low power loads an ideal solutions is provided by Nexperias Resistor Equipped Transistors (RETs). With the integration of biasing resistors they can provide a significant reduction in BOM items. Two common configurations are shown in Fig. 14. Because these internal resistors have higher tolerances than commonly used external resistors, RETs are suitable for switching applications where the transistor operates in either on- or off-state. This is why RETs are often referred to as digital transistors. RETs can act as load switches up to 600 mA and 80 V for a variety of loads, as displayed in Fig. 15. They provide a simple method that can be used to switch and drive loads directly from logic devices. In Configuration 1, the NPN RET serves as a low-side switch, enabling the resistive load or LED, or an inductive load which is connected directly to the battery to be switched. The important point to note here is that the voltage swing of the logic device such as a microcontroller is enough to switch the RET. In Configuration 2, the NPN RET is now used as a high-side switch in the control path, and is driving a PNP RET with the load switched directly by the logic input such as a microcontroller. Nexperia's standard 50 V RETs are to be found in many automotive applications. One typical application is converting signals from a low voltage, such as 3-3.3 V to the battery voltage of 12 V.

However, voltage can be as high as 24 V in trucks and 48 V in mild hybrid and electric vehicles. To provide more headroom for these voltages 80 V RETs are introduced. These devices can also withstand pulse tests in accordance with ISO 7637-2:2011, the standard that defines robustness against transients along the power supply bus. Nexperia's 80 V RETs have been tested and withstand the required 20 V across base-emitter junction.

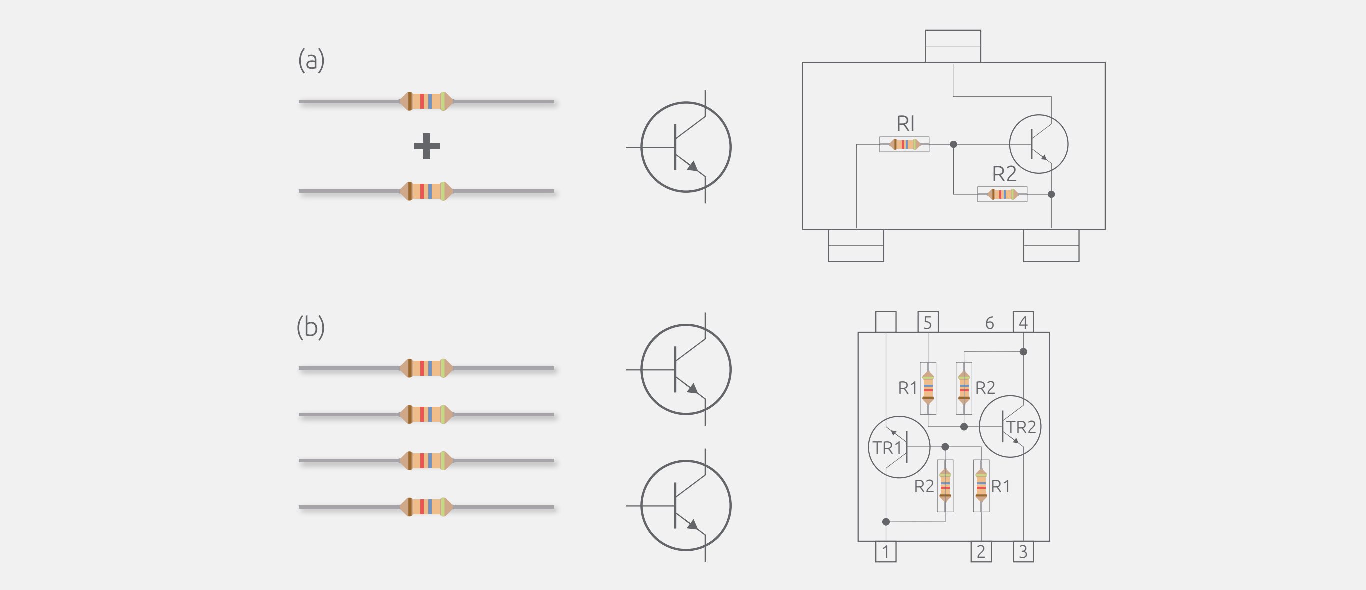


Fig. 14 Two common forms of RETs, two resistors and a transistor are integrated with a single NPN transistor (a), dual version with two transistors and four resistors (b)

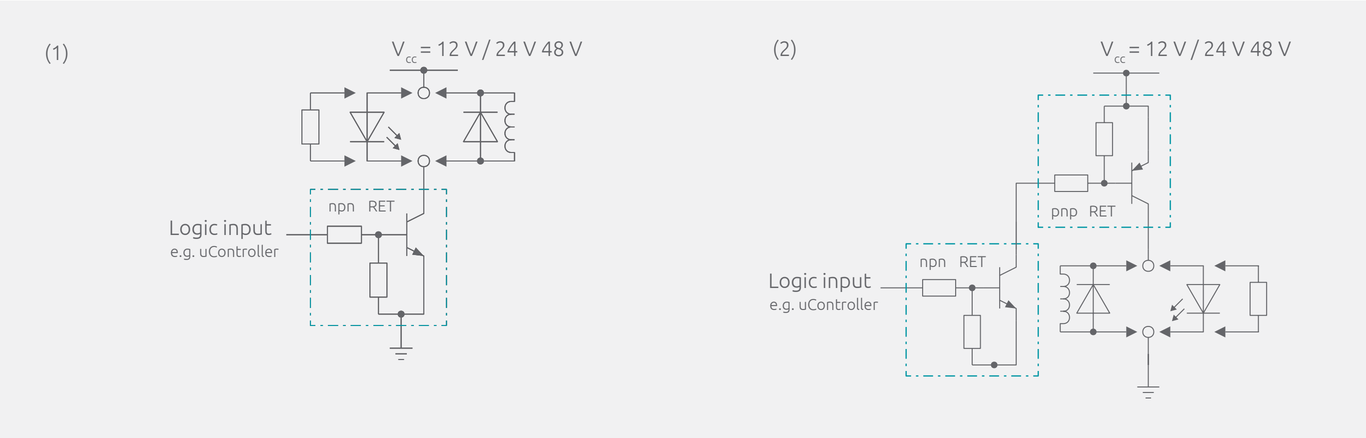


Fig. 15 Two circuit examples using RETs: Low-side switch (1), high-side switch (2).

Fig. 16 shows the switching characteristic of a RET plotting V_{CE} versus input voltage V_i. The condition required for an off-state is that the collector leakage current must be 100 µA at a collector-emitter voltage of 5 V. For safe turn-off, $V_{(ioff)max}$ must not be exceeded. When determining the on-state, $V_{i(on)min}$ must be considered. The circuit controlling the RET has to provide at least this voltage for a safe turn on. On-state is defined as a collector current of 10 mA while the collector-emitter voltage is 0.3 V. The datasheet V_i rating is valid for the defined test condition only. If a bigger collector current shall be switched the RET requires more base drive voltage $V_{i(on)}$.

It is also important to consider the same diagram at different temperature ranges. BJT switches become more effective as the temperature goes up, so they will safely stay on if temperature becomes higher. However, with increasing power densities in under the hood applications as well as a wider range of ambient temperatures due to global markets, the required device temperatures can go to the extremes. Nexperia RETs also come in 175°C maximum junction temperature capability, which simultaneously increases their power capability by 25%.

If the vehicle is required to operate in a cold climate, care has to be taken to ensure that the BJT stays in on-state, because at low temperatures the the BJT current gain goes down and the voltage drop V_{BE} increases, so a higher turn-on voltage is required. Table IV shows the dependency of the on- and off-state input voltages on the resistor divider configuration in RETs from Nexperia's NHDTC series RETs. For deeper insights on RETs, including basic topologies, naming conventions, more advanced application examples, explanations of datasheet parameters and curves along with their testing methods, failure mechanisms and overview of available packages, please refer to AN90024.

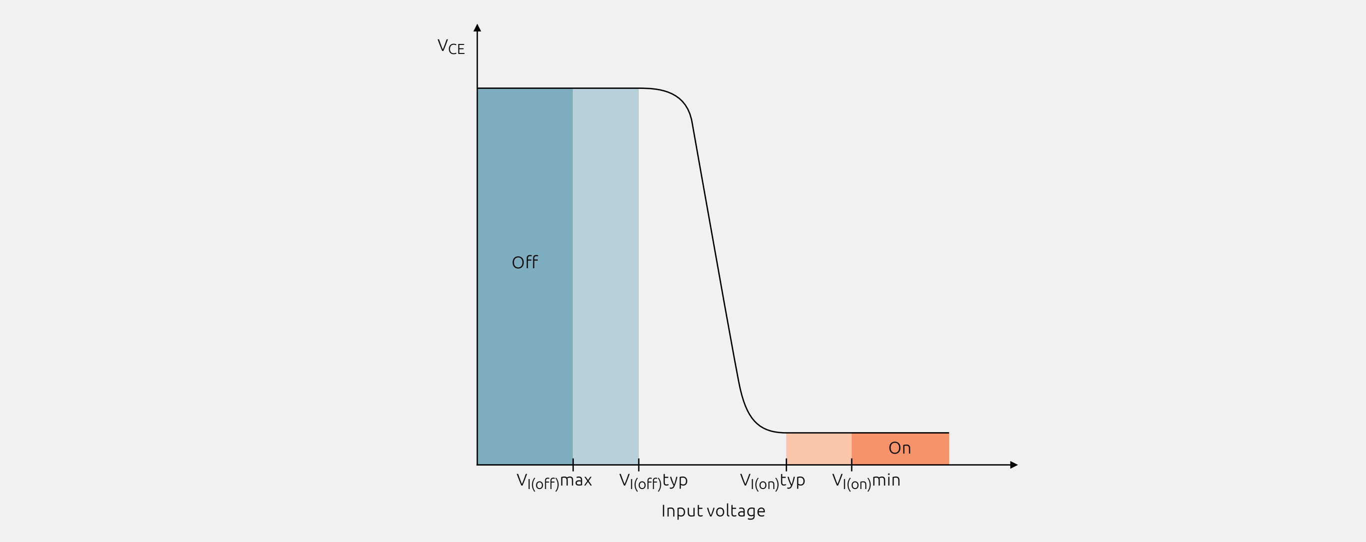


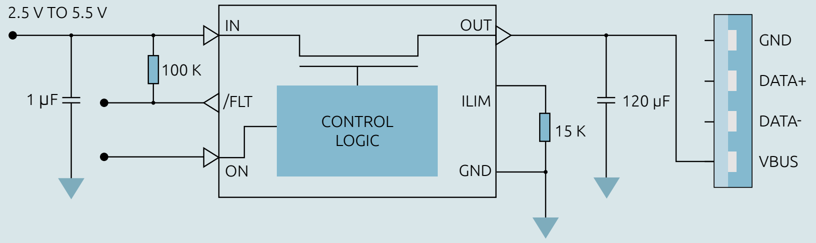
Fig. 16 Switching characteristic of a RET.

R1/R2 [kΩ/kΩ]	$V_{I(on)}$ min [V]	$V_{I(on)}$ typ [V]	$V_{I(off)}$ typ	$V_{(off)}$ max [V]	RET Type
10/10	2.5	1.8	1.15	0.8	NHDTC114ET
22/22	3	2.3	1.15	0.8	NHDTC124ET
47/47	5	3.3	1.15	0.8	NHDTC144ET
2.2/47	1.2	0.81	0.595	0.5	NHDTC123JT
4.7/47	1.4	0.95	0.625	0.5	NHDTC143ZT
10/47	1.6	1.22	0.690	0.5	NHDTC114YT

Table IV Dependency of the on- and off-state input voltages on the resistor divider configuration.

Integrated load switches, like the NPS4053-Q100, can be used to activate parts of the design instead the discrete alternatives [AN90052]. Integrated load switches inherently require less design-in effort, smaller board space and fewer external components as well as integrated protection functions, albeit they are typically produced for lower current ratings than their discrete solution counterparts. They might be ideally suited for applications with low power requirements and space constraints.

NPS4053-Q100 integrated load switch

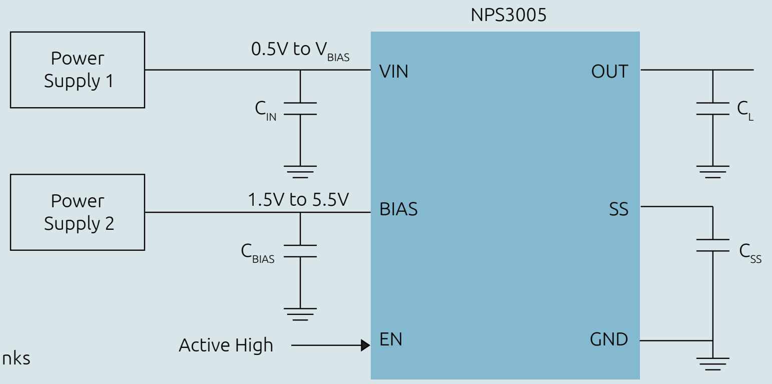


- Input voltage range: 2.5 V to 5.5 V
- Maximum continuous current: 2 A
- ON resistance: 55 mΩ
- Adjustable current limit: 110 mA to 2.5 A
- ±6 % current limit accuracy
- Constant current during current limit
- No body diode when disabled (no current path from pin OUT to pin IN)
- Active reverse voltage protection
- Built in soft start
- UL 62368 recognition
- SOT457 (TSOP6) and SOT8044-1 (HWSON6) package option
- 15 kV ESD protection as per IEC 61000-4-2

Some load switches are geared towards powering higher power peripherals. The NPS3005A/B-Q100 has 6A capability and low R_{DSon} with quick output discharge and soft start capabilities to increase system reliability. As with every IC it is of great importance to have low power consumption in sleep mode to save battery life.

NPS3005B-Q100 Integrated load switch

- Input voltage: 0.5 V to 5.5 V
- VBIAS voltage: 1.5 V to 5.5 V
- Low on-resistance: 14 mΩ
- 6A maximum continuous current
- 1.2V control voltage compatible
- Built-in quick output discharge (QOD)
    - Without QOD variant is NPS3005A
- Adjustable soft-start
- Over temperature protection
- AEC-Q100 Grade 1 Qualified (-40°C to +125°C)
- HWSON8 package (2mm x 2mm) with Side Wettable Flanks



The application of a load switch can limit inrush current to controllers, preventing damage to the microcontroller itself, pulling down the output voltage of the DC/DC converter or damaging the DC/DC converter itself. A typical placement of the Load switch can be seen in Fig.17 with the illustration of the change in the supply current.

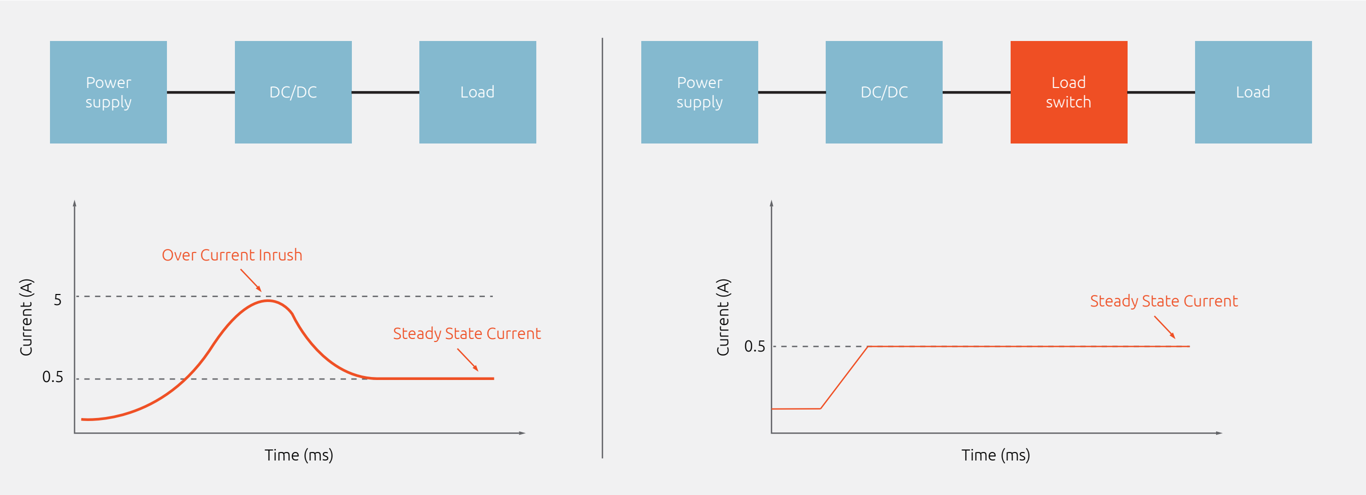


Fig. 17 Load switch placement block diagram and current limiting functionality

Load switches and smart high side switches also enable power sequencing to the complete board or individual controller. The sequencing can be controlled from an auxiliary, start-up controller and executed by integrated or discrete switches:

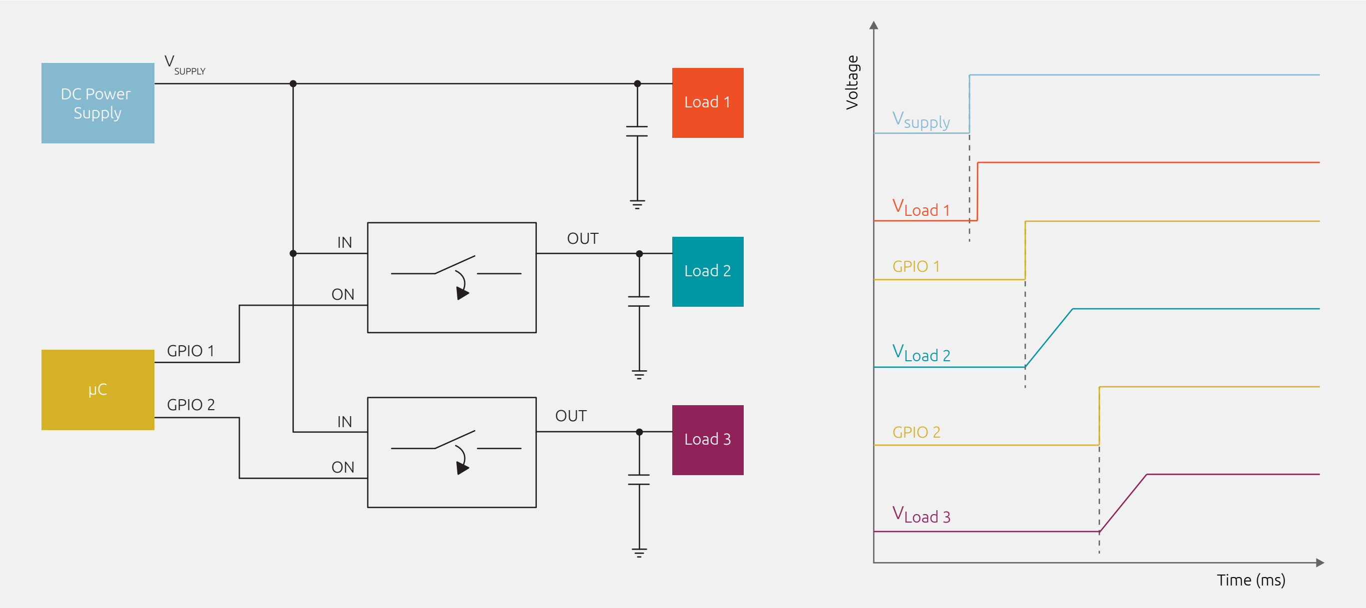


Fig. 18 Power sequencing with discrete or integrate load switches

5. Recommended products

Product	Description	Key part numbers
Power Management		
N-channel MOS	LFPAK33, 40 V/80 V/100 V, N-channel device, R_{DSon} 10-20 mΩ,	BUK9M11-40H, BUK9M15-40H, BUK7M20-40H, BUK9M24-80L
	LFPAK56D, 40 V/80 V/100 V, Half Bridge and Dual N-channel device	BUK9V13-40H, BUK7V4R2-40H, BUK9K13-40H, BUK9K49-80L
	SOT457, 40 V, N-channel device, R_{DSon} 19 mΩ and 23 mΩ	PMN20ENA, PMN30ENEA
	MLPAK33, 40 V/60 V/80 V, N-channel devices	BUK9Q4R6-40H, BUK9Q7R0-40H, BUK7Q4R9-40H, BUK7Q6R0-40H, BUK7Q7R5-40H, BUK9Q29-60E, BUK9Q14-80L
	DFN2020MD-6, 40 V, N-channel device, R_{DSon} 20-30 mΩ	BUK6D23-40E, BUK9D23-40E, BUK7D25-40E, BUK6D30-40E
Schottky Diodes	CFP3, 40 V / 60 V / 100 V low V_f, low leakage current Trench Schottky barrier rectifier	PMEG40T30ER-Q, PMEG60T20ELR-Q, PMEG100T30ELR-Q
Step down (Buck) converter	SOT23-6, 4.5 – 40 V V_{in}, 600 mA Synchronous Buck converter	NEX40400-Q100
Zener diodes	CFP3, 3 – 12 V, 400 mA, 5% tolerance	HPZR-C12-Q
	DFN1006(BD)-2, 3 – 12 V, 200 mA, 2% and 5% tolerance	BZX884 series, PZU884LS-Q series
Gate driver MOS	4 A peak high-performance dual MOSFET gate driver	NGD4300-Q100
Gate driver GaN	Ultra-Fast E-GaN HEMT Gate Driver	NGD11000
Power distribution		
Signal MOSFET	SOT363, 30V and 60V dual and complementary pair Trench MOSFETs	NX3008CBKS
	SOT323, 30 V and 60 V, N-channel Trench MOSFET	NX3008NBKW
	DFN1010B-6, dual N-channel Trench MOSFET	PMXB360ENEA
	DFN2020MD-6, >30 V, dual N-channel Trench MOSFET	PMDPB56XNEA
Signal BJTs	SOT ~300 mW, 20 V – 100 V power bipolar transistor	BC817K-16, BC817K-25, BC817K-40, PBSS4160T-Q, PBSS4140U, PBSS4160U, PBSS8110D, PBSS4021NX-Q, PBSS4330X
	DFN ~300 mW, 10 – 100 V power bipolar transistors	BC54PA-Q, BC54-10PA-Q, BC54-16PA-Q, PBSS2515MB, PBSS2540M, PBSS2540MB, PBSS4260QA, PBSS4310PAS-Q, PBSS4620PA-Q
RETs	SOT23, Energy efficient 600 mA 40 V NPN and PNP 150°C and 175°C rated	PBRN113ZT-Q, PBRN113ET-Q, PBRN123YT-Q, PBRP123ET-Q, PBRP123YT-Q
	SOT23, Energy efficient 100 mA 50 V NPN and PNP 150°C and 175°C rated	PBDTC114ET-Q, PBDTC123JTH-Q, PBDTA114ET-Q, PBDTA123JTH-Q
	SOT23/SOT363, 80 V NPN and PNP single and double	NHDTC124ET-Q, NHDTA114YT-Q, NHUMH10-Q, NHUMD2-Q
	SOT363 100 mA 50 V double RETs 175 mΩ rated	PUMH7H-Q, PUMD6H-Q
Shunt regulators		TL431AFDT-Q and TLVH431N family
Integrated load switch	5.5 V, 2 A, 55 mΩ, TSOP6 and HWSON6 package	NPS4053GV-Q100 and NPS4053GH-Q100
LDO	40 V/300 mA/150 mA general purpose LDO with 5 µA ultra low I_q	NEX90530BPA-Q100, NEX90515BPA-Q100
	40 V/300m A/150 mA tracking LDO with 5 µA ultra low I_q	NEX91x30-Q100, NEX91x15-Q100
	40 V/70 mA tracking LDO, SCT595-5 and SOT23-5 package	NEX91207DF-Q100, NEX91207DE-Q100

4. References

Nexperia handbooks

MOSFET and GaN FET application handbook

Bipolar Junction Transistor (BJT) Application Handbook

Diode fundamentals, characteristics and applications

Application notes

AN50007 | Applying ISO standard conducted transients to MOSFETs in 12 V, 24 V and 48 V systems

AN50020 | MOSFETs in Power Switch applications

AN90011 | Half-bridge MOSFET switching and its impact on EMC

AN90024 | Resistor Equipped Transistors (RETs): Key parameters and application insights

AN90052 | Nexperia load switch ICs compared to discrete solutions

AN11550 | Performance of Schottky rectifier in CFP15 package in low power adapter

Other collaterals

Whitepaper | RET_devices

Leaflet | Electronics_power_management_load_switch

Blog | Consider Low VCEsat BJTs for High Power Supply Efficiency

Blog | Need a Stable Voltage or Current Source? Sometimes it Pays to be Discrete!

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